# NUCLEAR

## Energy and Environment Compendium

Los Alamos
NATIONAL LABORATORY

# NUCLEAR

## Energy and Environment Compendium

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CLIMATE
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LALP-04-026

October 2004

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Los Alamos NM 87545

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## Nuclear Technology and Applications Research at Los Alamos National Laboratory



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# Nuclear Technology and Applications Research at Los Alamos National Laboratory

## Nuclear Energy Research at Los Alamos National Laboratory

Los Alamos conducts research in both nuclear fission and nuclear fusion. Nuclear fission achieves energy release by splitting heavy atoms (as in a present-day nuclear reactor), whereas nuclear fusion achieves energy release by combining light atoms (as in the process occurring in the core of a star). The Nuclear Technology and Applications Program leads the fission effort while fusion research is managed by Nuclear Fusion Energy Sciences.

## Nuclear Technology and Applications Research

Technology development programs carried out within the Nuclear Technology and Applications portfolio aim at major national and international needs, including

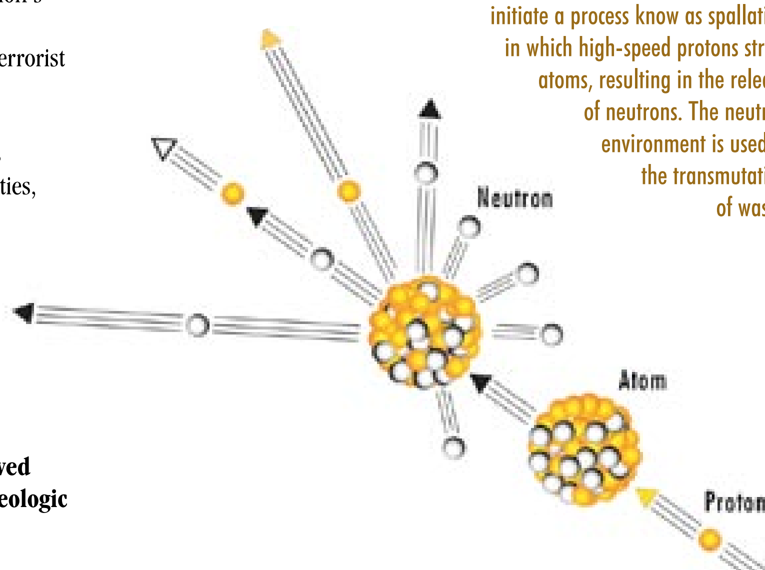
- New nuclear energy technology that supports the goals and objectives of the President's National Energy Policy;
- Technologies that support recommendations on advanced nuclear fuel cycle development made by the directors of six leading Department of Energy national laboratories to the Secretary of Energy;
- Near-term space exploration missions that require significant levels of electrical power for their success;
- Radioisotopes needed nationwide for disease diagnostics and treatment;
- Efforts to ensure continued highest levels of safety of the nation's 100 operating reactors; and
- Efforts to maximize the security of nuclear reactors against terrorist attack or sabotage.

The nuclear technology development and applications efforts at Los Alamos support these efforts through combinations of unique facilities, demonstrated nuclear materials capabilities, sophisticated nuclear system design, and safeguards expertise.

## Current Science and Technology Challenges in Nuclear Technology and Applications Research

- **New technology systems to effectively deal with long-lived radionuclides in nuclear waste that drive long-term geologic disposal requirements**—Developing and demonstrating efficient technologies that separate plutonium and higher actinides from used fuel discharged from power reactors and that effectively use recovered materials in reactor or accelerator-based nuclear systems to minimize through transmutation of nuclear waste long-lived radionuclide inventories, that would otherwise be discharged to the environment, are equally important components of meeting this challenge.
- **New technologies to ensure nuclear fuel cycle and reactor systems deployed for future energy needs exhibit highest levels of proliferation resistance**—Integrating and optimizing technologies *a priori* for nuclear materials safeguards and nuclear materials separations represent development approaches that are needed to meet this challenge.
- **Sophisticated analysis capabilities to understand nuclear energy contributions to future national and global energy sustainability**—Understanding end-use scenarios and technology competitiveness, achieved through energy-environment-economics simulation tools, can guide nuclear energy technology development.
- **Increased production of radioisotopes required for medical and scientific applications**—Meeting the challenge with a new Isotope Production Facility at LANSCE and plans for new, dedicated accelerator facilities can meet this challenge.

A proton accelerator can be used to initiate a process know as spallation in which high-speed protons strike atoms, resulting in the release of neutrons. The neutron environment is used in the transmutation of waste.



- **Reliable and safe production of nuclear energy for space applications are required by NASA for upcoming missions to Mars and the Jovian moons**—Designing robust space reactors that need no terrestrial nuclear testing, as well as manufacturing appropriate nuclear fuels, will meet this challenge in a safe, cost-effective manner.
- **Threat assessment (safety, terrorist, sabotage) of nuclear facility vulnerabilities is a key need**—Developing sophisticated risk assessment tools and advanced simulation capabilities based upon modern computing environments is the key resource to answer this challenge.

## Nuclear Technology and Applications Capabilities

- **Nuclear materials chemistry and separations**—Los Alamos has many scientists in the Chemistry and Nuclear Materials Technology divisions that have a unique combination of innovative process design and operational experience. The Plutonium Facility (TA-55) is a major national resource that allows technology demonstration in nuclear materials environments. Plans by the Seaborg Actinide Science Institute for new facilities available to outside researchers will further enhance this capability.
- **Nuclear fuels production**—Facilities at TA-55 for fuels production are unique in the DOE laboratory complex. Additionally, experimental capabilities are being enhanced by new initiatives in sophisticated simulations for novel nuclear fuels properties and performance.
- **Nuclear system design**—Modeling and simulation using codes such as MCNPX and TRAC contribute to Laboratory researchers' novel design efforts for applications such as space reactors.
- **The Isotope Production Facility and associated hot cell and isotope separations facilities**—The LANSCE-based Isotope Production Facility is the major national resource for producing neutron-deficient radioisotopes. Site-located hot cells and supporting analytical and separation capabilities allow Laboratory scientists to meet external customer needs on a timely basis.
- **Nuclear safeguards technology**—Los Alamos is the only national laboratory with experience in developing and applying nuclear safeguards technology to foreign fuel fabrication, nuclear materials storage, and reprocessing facilities in Russia and Japan.
- **Experimental facilities and theoretical capabilities for nuclear data**—The LANSCE facility is a major U.S. resource for measuring proton- and neutron-induced nuclear reaction cross sections over energy ranges from milli electron volts to hundreds of megaelectron volts. This experimental capability is complemented by an internationally recognized effort in the theoretical analysis and modeling of cross sections and in the creation of computer-based data libraries for use in nuclear design codes.
- **Energy and nuclear fuel cycle modeling**—The Laboratory has developed and applied sophisticated models of the nuclear fuel cycle to examine material flows, economics, and waste disposal requirements for advanced nuclear systems. Such fuel cycle models are also coupled into energy-economic-environment models that allow future energy demand and supply scenarios on national, regional, and global bases to be examined. These models are used to examine the competitiveness of nuclear energy with other options and to ascertain policy impacts such as carbon taxes on fossil fuels on nuclear market shares.
- **Risk and threat assessment**—The Laboratory has decades of history in developing and applying advanced methods for probabilistic risk assessment (PRA). While such PRA methods have been applied to analysis of severe reactor accidents, they are now being applied to nuclear facility safety and security. Complementing PRA methodology development and application has been the creation of sophisticated tools for reactor safety analyses, in particular the TRAC code—a principal resource for the Nuclear Regulatory Commission (NCR).

The LANSCE linear accelerator is being used to develop nuclear data and transmutation science and will soon house a major experiment to further the development of new materials and fuels for the transmutation of nuclear waste.

## Nuclear Fusion Energy Sciences

Fusion energy, the process which powers the stars, involves fusing together light atoms to release nuclear energy. It offers the hope of a nearly limitless supply of energy to mankind, with the fuel commonly found in seawater, and has no global warming emissions. Unlike nuclear fission, which happens easily when you stack a pile of heavy metal, fusion reactions are very difficult to ignite on Earth.

At Los Alamos, research into the control of the processes of nuclear fusion began in the early 1950's and continues to this day. Fusion energy research is supported by the DOE Office of Science, Fusion Energy Sciences branch. Our research is conducted along two principal approaches. The first uses powerful magnets to make a "bottle" to contain the hot plasmas, and the second uses inertial compression, either with lasers or ion beams. These are referred to as Magnetic Fusion and Inertial Fusion (see p.15). Learn more about Los Alamos's Fusion Energy Sciences Program at **http://fusionenergy.lanl.gov**.

# Transmutation of Nuclear Waste

## The Challenge: Addressing Pressing Nuclear Energy and Waste Management Issues

Before additional nuclear power capacity can be developed, the concern for management of nuclear waste produced by commercial nuclear power plants must be addressed. Realizing this necessity, Los Alamos created the Advanced Fuel Cycle Initiative (AFCI) Program to address such pressing nuclear issues as nuclear energy and waste management. As a result, Los Alamos National Laboratory is newly focused on the coordination of expertise, research, and development efforts related to non-weapons nuclear technology and applications. One of the first areas on which the Laboratory is concentrating its efforts is nuclear power.

## Los Alamos Innovation: Transforming Radioactive Materials into Less Harmful Substances

With Los Alamos's expertise and research in both accelerator design and target technology, the AFCI Program is developing the technology base for nuclear waste transmutation (the nuclear transformation of long-lived radioactive materials into short-lived or non-radioactive materials), and plans to demonstrate its practicality and value for long-term waste management. The Laboratory has unique capabilities for fuel development for fast and thermal spectrum multipliers, lead-bismuth technology, materials testing, and modeling of advanced separations technologies. Los Alamos has also developed a novel concept for separating uranium from spent nuclear fuel.

Thus far, Los Alamos and its partners have built and operated the front end of a high power accelerator and built and operated a liquid-lead eutectic loop for testing. They have developed and fabricated transmutation (plutonium-nitride) fuels and performed numerous system studies on various waste transmutation schemes to determine the most viable approach to address the nuclear waste issue. And they have obtained nuclear cross-section data and evaluations for isotopes of interest for transmutation.

## The Impact: Nuclear Energy as a Safe and Secure Energy Alternative

While the AFCI Program is working on methods to drastically reduce the amount of nuclear waste currently in storage, the goal of the program is to develop the technology that will transition the U.S. into a closed fuel cycle with a more economical and less wasteful use of nuclear materials by reducing the long-term radiological impact of waste and enabling development of a simpler, cheaper repository. This can also reduce proliferation risks, thereby improving long-term prospects for nuclear power.

Uranium (VI) nitrate crystals, part of advanced separations concept for spent fuel recycling. Los Alamos researchers are evaluating a process to crystalize uranium (VI) nitrate from spent nuclear fuel dissolved in nitric acid.



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# Isotope Production and Applications

## The Challenge: Supplying the Radioisotope Needs of Medicine and Science

Los Alamos National Laboratory is one of three sites that produce and distribute stable and radioactive isotopes for the Department of Energy's Office of Nuclear Energy, Science, and Technology. The radioisotope program at Los Alamos's Neutron Science Center (LANSCE) has been producing radioisotopes for more than 20 years, making it one of the most successful and visible ongoing endeavors in the nationwide production and distribution of isotopes. Without the production capabilities at LANSCE and other national and international facilities, the DOE would not be able to meet the needs of its radioisotope customers. A major milestone was reached in February 2004 with the dedication of a new target irradiation facility at LANSCE for the production of medical research isotopes.

## Los Alamos Innovation: Creating Stable and Radioactive Isotopes

Unique radioactive material handling facilities and capabilities in accelerator technology, radiochemistry, chemical processing, and synthetic chemistry allow the Laboratory to offer a variety of products and services. LANSCE and the TA-48 main radiochemistry site hot cell facilities create accelerator-produced isotopes, and the CMR wing 9 hot cell facilities perform chemical processing of reactor irradiated targets. Los Alamos can separate stable and radioactive elements with electromagnetic isotope separation techniques and distribute inventories of americium-241 and other actinides.

## The Impact: Meeting the Demand for Commercial and Clinical Radioisotopes

The combination of Los Alamos's unique facilities and radioactive materials handling expertise is essential to this important national program. To ensure the continuing demand for radioisotopes is met, LANSCE is expanding its facilities by designing and constructing a 2-level $19.9 million Isotope Production Facility that will ensure a dedicated year-round supply of radioisotopes when combined with similar isotope production capabilities at Brookhaven National Laboratory and supplemented by international collaborations. It will also provide significant opportunities for applications at the intersection of the Laboratory's radiochemistry and biochemistry capabilities. The main customer is the DOE Office of Isotopes for Medicine and Science, but products and services are also distributed to an extended customer base of over 250 institutions, such as hospitals, universities, other research institutions, and industry.

These hot cells in Los Alamos are used to perform chemical separations to isolate and purify the accelerator-produced medical isotopes at LANSCE.

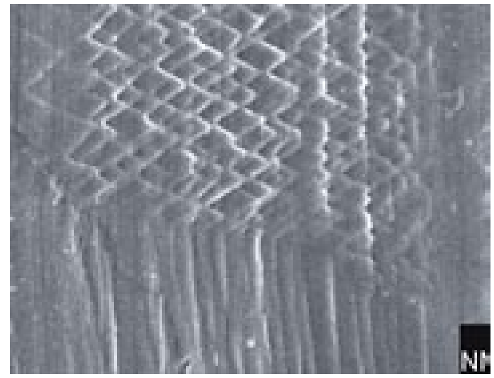
# Structural Materials for the Advanced Fuel Cycle Initiative

## The Challenge: Identifying Reactor Materials for the Advanced Fuel Cycle Initiative

Reactor materials for the Advanced Fuel Cycle Initiative (AFCI) must withstand high-energy proton and neutron fluxes at temperatures ranging from 400° to 600°C. This project determines the effect of high-energy proton and neutron irradiation on the mechanical properties of structural materials under prototypical conditions of irradiation, temperature, and flux. Prototypic materials are

- Ferritic martensitic steels,
- Austenitic steels, and
- Refractory materials.

The goal is to obtain mechanical properties after irradiation to doses of 200 dpa at temperatures of up to 600°C. The project also addresses materials needs for the Generation IV reactor program with the challenge to push temperatures even higher.



Above: Scanning Electron Microscope (SEM) micrograph showing coarse slip bands on the outer surface of a 316L stainless steel 3 pt. bend specimen after irradiation and testing at 350°C to a dose of 10 dpa in a 570 MeV proton beam.

## Los Alamos Innovation: Determining the Effect of High-Energy Proton and Neutron Irradiation on the Mechanical Properties of Structural Materials

Los Alamos is using the following three capabilities to address three key issues:

1. Chemistry and Metallurgy Research (CMR) hot cell capabilities for handling and testing radioactive materials after irradiation in high-energy proton or neutron flux.
2. Atomistic modeling capabilities and expertise to extrapolate the data to conditions not tested experimentally.
3. 800 MeV, 1 mA accelerator for performing some of the materials irradiations.

Below: Los Alamos researchers use a Leitz MM5 Metallograph to view the microstructure of irradiated materials in the CMR hot cells.

## The Impact: Managing Nuclear Waste and Designing Advanced Reactors

The ultimate goal of this project is to use the mechanical test data and modeling capabilities to determine structural design allowables for AFCI components. This enables the determination of material lifetimes for specific components in the AFCI program as well as the Generation IV reactor program. Los Alamos has the ability to overcome obstacles in managing nuclear waste and designing advanced nuclear reactors.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# Yucca Mountain Project Radionuclide Transport

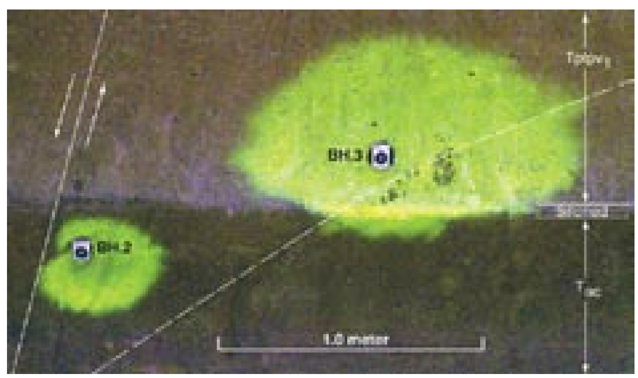
## The Challenge: Ensuring Yucca Mountain Meets Waste Repository Requirements

Under stringent quality assurance procedures, Los Alamos has played a key role in preparing the programmatic documents used as the technical justification for the Department of Energy (DOE) to propose Yucca Mountain as the site of the first high-level radioactive waste repository. These documents represent the state of our scientific knowledge about the site and the potential for the geologic rock layers to retard the migration of radionuclides. The numerical models developed by Los Alamos were used directly in the performance assessment system model that was used to show that the Yucca Mountain site meets the regulatory requirements for a high-level radioactive waste repository.

## Los Alamos Innovation: Characterizing the Hydrology and Geology Beneath Yucca Mountain

Moving forward represents the culmination of several decades of integrated research by Los Alamos scientists and collaborators on the hydrology and radionuclide transport characteristics of the geologic layers and the underlying aquifer beneath Yucca Mountain. Los Alamos has assembled an integrated program with laboratory experiments, field testing, and numerical modeling that has

- Characterized field samples;
- Measured the solubility and sorption of radionuclides;
- Studied transport rates in laboratory columns;
- Investigated the role of colloids in facilitating radionuclide transport;
- Performed hydrologic and tracer testing in the saturated and unsaturated zones;
- Calculated the conceptual model and determined model parameters;
- Assessed the groundwater system with hydrochemical sampling and data interpretation;
- Predicted radionuclide migration in the water table by modeling the unsaturated zone;
- Modeled flow and transport in the saturated zone to understand the hydrology, integrate the field data, and predict radionuclide transport; and
- Designed small-scale models of specific field tracer tests to understand the transport mechanisms and determine parameters for large-scale models.




## The Impact: Removing Barriers to the Continued Use of Nuclear Energy

Based on Los Alamos's work, the Department of Energy was able to investigate all aspects of the issue, including engineering the underground facility, designing the manmade barriers, characterizing and predicting the migration of radionuclides in the geosphere, and isolating waste with the highest probability of public safety for acceptable time periods. The science performed in the Yucca Mountain project can not only renew progress in solving problems that have prevented the continued and expanded use of nuclear energy, but it also can be applied to other environmental water quality projects.

# Space Reactors

## The Challenge: Safe and Reliable Space Power and Propulsion

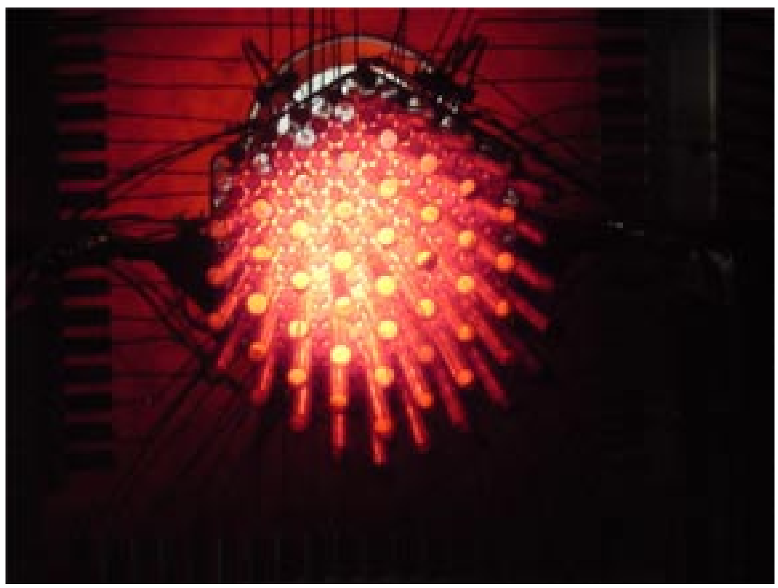
Los Alamos began a low-level effort in the mid-1990's to rejuvenate interest in space fission power and propulsion systems. The focus of the Laboratory's approach was on simple, highly testable systems that could enable space missions.

## Los Alamos Innovation: Highly Testable Space Reactor Designs

In 1998, Los Alamos began working closely with NASA to design and fabricate potential space fission power reactor cores (unfueled), with a particular emphasis on testability. In 2000, realistic testing of one such core was initiated, with resistance heaters used to closely mimic fission heat deposition. In 2001, the core was coupled to a power conversion subsystem and an ion thruster to provide an end-to-end nuclear electric propulsion breadboard. Also in 2001, NASA began expressing interest in the development of space fission systems. The Los Alamos-led team continues to perform design, analysis, and testing related to a variety of space reactor concepts. Los Alamos is currently the reactor design lead for NASA's Jupiter Icy Moons Orbiter (JIMO) Project.

The Los Alamos-led team continues to demonstrate that innovative, highly testable space fission systems can be devised to enable numerous missions. The proposed designs facilitate conversion of paper reactor designs into actual working hardware. Designs emphasize test effectiveness (i.e., the ability to complete highly realistic non-nuclear testing). Systems are designed to be resistant to radiation damage and to have modest fuel burnup requirements, further increasing the worth of realistic non-nuclear testing. Numerous hardware tests have been performed to confirm the potential performance of the proposed systems.

SAFE-100 core simulator test performed during development of a reactor for NASA's Jupiter Icy Moons Orbiter (JIMO).



## The Impact: Space Missions Requiring High Power Where Solar Power is Not Available

Space fission power and propulsion systems could enable numerous exciting space missions. Space fission systems are especially attractive for space missions requiring high power and/or missions operating in environments where solar power is not readily accessible. Potential missions include long-duration travel to the lunar or Martian surface and NASA's Jupiter Icy Moons Orbiter.

# Spent Fuel Treatment

## The Challenge: Reducing the Life Span of Spent Fuel and Recovering Energy Value

A nuclear power plant generates electricity using the energy released from the fission of certain isotopes present in the fuel, mainly uranium-235 and plutonium-239. The fission process produces many radioactive fission product elements. As the fuel is consumed in the reactor to release energy, the reduction in the amount of fissile isotopes in the fuel, and the build-up of fission products that absorb neutrons, makes replacement of some of the fuel elements necessary. Because radioactive decay produces heat, the spent fuel is removed from the reactor and stored underwater to cool. The spent fuel contains substantial amounts of energy in the remaining fissile elements and the "ashes" or fission products from the "burning" of the nuclear fuel. In the once-through fuel cycle, the spent fuel is allowed to decay for decades, until it is easier to package it in a container for final disposal in an underground repository. The repository must be capable of retaining some of the radioactive elements in the spent fuel, such as plutonium and technetium, for hundreds of thousands of years.

The goal is to separate the spent fuel into packages, thereby reducing life span and recovering energy value. The challenge is to accomplish this economically, safely, and with advanced operational safeguards. The current technologies used to treat fuel in France, the United Kingdom, Japan, and Russia recover uranium and plutonium from the fuel for recycle. However, the costs are high and improved separation of the fission products and other actinide elements is needed to optimize the overall fuel cycle and increase proliferation resistance.

## Los Alamos Innovation: Revolutionary Separation Approaches

The work at Los Alamos on spent fuel treatment processes ranges from evolutionary to revolutionary. This includes developing a crystallization process based on standard industrial methods for recovering uranium, neptunium, and plutonium from spent fuel that has been dissolved in nitric acid and evaluating a revolutionary approach to separating actinides from the fission products in spent fuel based on aqueous carbonate solutions. Los Alamos's innovations have also allowed for the exploration of actinide and fission product separations in ionic liquid solutions and the exploration of high-temperature methods to reduce the cost of decladding the spent fuel and to remove selected fission products from the fuel. The Laboratory has also been developing selective and energy-efficient membrane-based separation systems as well as new nuclear fuel structures to simplify the recovery of the actinides from the fission products after the fuel is used.

## The Impact: Recycling Spent Fuel and Reducing Waste

New technology is under development at Los Alamos to recover the energy value and more effectively manage the fission products. These technologies separate the components of spent fuel to recycle actinide materials for further use in power production while packaging the fission products more efficiently for disposal, transmutation, or other uses. The result would greatly increase the amount of waste the repository can accept, and the waste will decay to levels similar to those of natural uranium ores in a few hundred years.

A loop crystallization apparatus being tested to form crystals of uranium (VI) nitrate in a continuous process. The crystallization method could provide a more cost effective way to separate uranium from a solution of spent fuel dissolved in nitric acid.



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# Physics Code Development

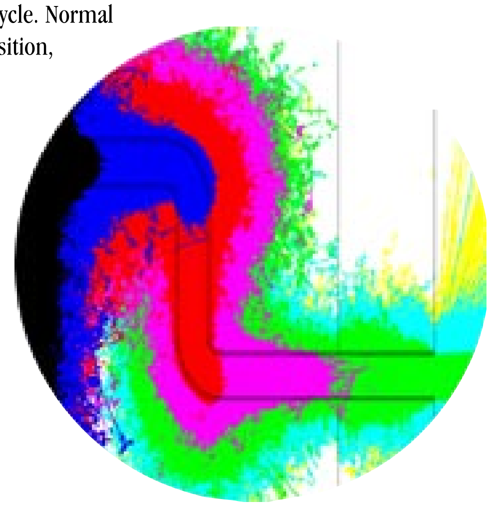
## The Challenge: Creating Accurate Radiation Transport Computer Simulations

Accurate radiation transport computer simulations are fundamental in the design and operation of nuclear facilities. Such codes are important for reactor design, criticality determination, shielding design, dosimetry and heating calculations, and safety parameters estimation. Isotopic burnup simulation is key for waste transmutation, but capture and decay data must be modeled for thousands of isotopes in ground and metastable states. Therefore, the computer code must accurately simulate reactor geometry, particle flux, and changing elemental fuel composition at varied temperatures.

## Los Alamos Innovation: MCNPX and CINDER'90 Codes

An experienced team of researchers is using the Monte Carlo radiation transport simulation approach, including both the MCNPX (3-D Monte Carlo) and the CINDER'90 (burnup) codes. The MCNPX code simulates the tracking and interactions of all particles over a wide range of energies and uses standard evaluated nuclear data libraries or in-line models when libraries are lacking. While building upon Los Alamos's work in Monte Carlo simulations, dating back to the Manhattan Project era, new techniques are being developed to increase simulatioin accuracy. The CINDER'90 code tracks nuclide evolution in a system when subjected to a pre-determined periodic neutron flux and is now being adapted to handle proton flux. Preliminary coupling was first enabled with the Monteburns code, and Los Alamos now seeks to fully integrate the two into a new package. Enabling a continually changing material description in MCNPX through the addition of the CINDER'90 burnup routines will give an accurate picture of material evolution through the entire reactor run cycle. Normal MCNPX tallies also enable the calculation of all standard parameters such as criticality, energy deposition, and particle flux at any point in the run cycle.

Example calculation showing neutron streaming through a waveguide penetration in a high-power industrial accelerator.



## The Impact: A Wide Range of Applications

The MCNPX project has over 1,100 users from more than 250 U.S. and international institutions. Applications include

- Reactor and accelerator-based transmutation,
- Design of nuclear propulsion reactors for space missions,
- Neutron scattering experiments at spallation targets,
- Reactor and accelerator health physics,
- Medical applications (proton, photon, electron, and neutron therapy),
- Oil well logging,
- Irradiation facilities design and analysis,
- Radioisotope production,
- Neutral and charged particle radiography, and
- Detectors and experiments for nonproliferation and homeland defense.

Nuclear facility design relies upon radiation transport simulation, and Los Alamos's codes already ensure safe operation for existing installations. Recent notable uses for the Los Alamos code include

- Calculations of accurate radiotherapy doses delivered to patients with tumors,
- Verification of water on Mars, as published in *Science* (July, 2002), and
- Design of the Oak Ridge Spallation Neutron Source target and shielding.

This project also includes the development of parameter calculations for externally driven criticality sources and the pursuit of new variance reduction, tallying, and error analysis techniques.

# Thermal-Hydraulic System Code Development and Applications

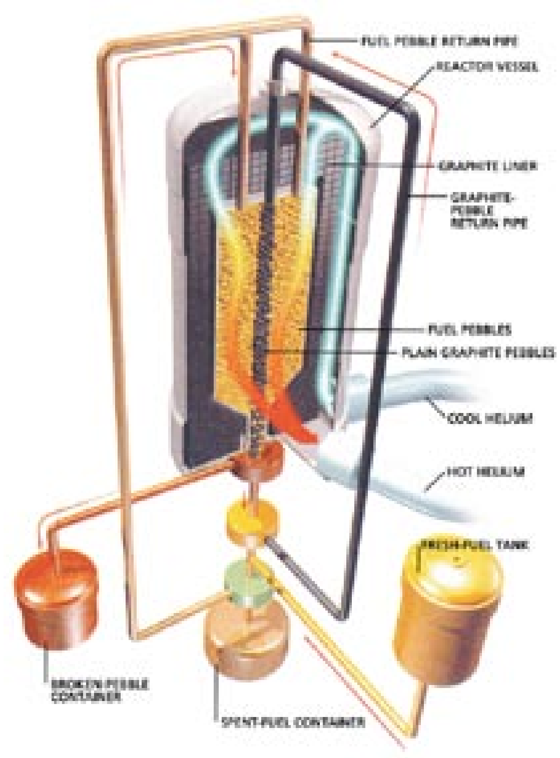
## The Challenge: Modeling Nuclear Reactor Safety

In order to assure the safety of nuclear reactors, independent safety analyses are performed using best-estimate thermal-hydraulic codes. The TRAC/RELAP Advanced Computational Engine (TRACE) code, being developed by Los Alamos and other institutions for the U.S. Nuclear Regulatory Commission (NRC), has been used to model nuclear power plants and simulate accident scenarios to show that safety systems can bring the plant to safe shutdown conditions.

## Los Alamos Innovation: The TRAC/RELAP Advanced Computational Engine

The TRAC/RELAP Advanced Computational Engine has been under continuous development by Los Alamos for the NRC since 1970. The TRACE code continues to evolve with increasing understanding of complex 2-phase, multi-component fluid phenomenology. After sponsoring multiple codes for over 2 decades, the NRC has selected TRACE as the sole platform for future development. Los Alamos plays a key role in an ambitious multi-institution development program to modernize and expand the existing code capabilities. As the NRC considers pre-application review of new reactor concepts such as the Pebble Bed Modular Reactor and the Simplified Boiling Water Reactor, Los Alamos is in a position to provide developmental and analytical support. Laboratory expertise is further leveraged by code development support for the Knolls Atomic Power Laboratory (KAPL), which has chosen TRACE as their best-estimate code.

Illustration of an advanced GEN-IV pebble bed modular reactor.




## The Impact: Safer Nuclear Power Plants and Facilities

In support of the Accelerator Transmutation of Waste program, TRACE has been updated to include liquid-metal fluid properties and to enable the tracking of trace species. A TRACE model of the Los Alamos DELTA loop facility, a liquid lead-bismuth materials test loop, has been developed and used to simulate actual test runs. Recent TRACE code development tasks have sought to provide new Pebble-Bed core, materials, and component models, as well as revised channel modeling for the simplified boiling water reactor. Enhancements include three-dimensional fuel sphere-coolant heat transfer capabilities for the pebble bed modular reactor, and modeling capabilities for the water rods and partial-length fuel rods associated with the advanced boiling water reactor fuel designs. Additional implicit heat structure development support for KAPL will reduce run-times on key design basis accident analyses. In the future, Los Alamos scientists look toward developmental tasks in support of the GEN-IV reactor concepts, as well as the potential for hybrid code development, coupling TRACE to computational fluid dynamic and/or reactor physics analysis kernels.



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# Assessing the Vulnerability of Nuclear Installations

## The Challenge: Understanding Nuclear Facility Vulnerabilities and their Consequences

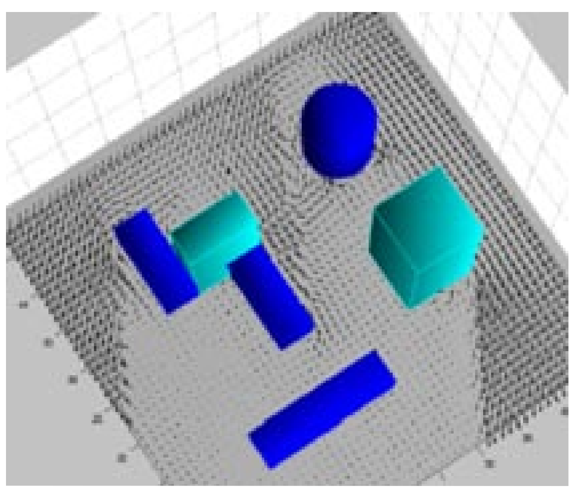
Los Alamos National Laboratory has been working with the Department of Energy, the Nuclear Regulatory Commission, and Sandia National Laboratories to support the development of a robust methodology to analyze potential threats to nuclear installations. This effort has led to capabilities and tools for a flexible approach to vulnerability assessment (VA) based upon the threat to a facility. Los Alamos is capable of providing the following information in support of facility VA's:

- Identification of threat sources, threat attributes, and potential targets;
- Identification of possible attack scenarios, including assessment of likelihood and consequences;
- Evaluation of existing protection and benefits of identified improvements.

## Los Alamos Innovation: Using Probablistic Risk Assessment and Other Analysis Tools

The same technologies used in assessing postulated nuclear facility accidents and their consequences can be applied to postulated terrorist attacks on those same facilities. These technologies include

- **Probablistic Risk Assessment (PRA)—**Risk is a metric for comparing attack scenarios, requiring estimates of the probability of occurrence as well as conditional probability of consequences given the attempt. The primary tool for evaluating risk is the Logic Evolved Decision tool, which uses logic models and approximate reasoning to produce estimates of attempt probability through qualitative and subjective inputs.
- **Interior Aerosol Transport Modeling—**Calculation of aerosol transport in buildings is fundamental to most nuclear safety issues. Los Alamos uses many tools to estimate the transport of aerosol particles through a building and its ductwork to the environment. These tools range from simple calculations to complex 3-D flow codes.
- **Atmospheric Dispersion Modeling—**Atmospheric dispersion is the key transport mechanism for the release of most hazardous materials, including nuclear materials. Los Alamos utilizes industry standard and in-house tools to evaluate atmospheric dispersion. Tools include the Los Alamos-modified INPUFF code and the Los Alamos QWIC-URB and HIGRAD codes. The INPUFF code utilizes a Gaussian puff model for computational efficiency. At the other extreme, HIGRAD resolves 3-D flow field effects with realistic meteorology (near-field atmospheric dispersion). QWIC-URB provides an intermediate approach that employs empirically based multi-dimensional effects in the building wake regions, yielding improved accuracy over the far-field approach without the computational penalty associated with a full computational fluid dynamics analysis.



A QUIC-URB computer simulation of the air flow around a group of buildings. Wind vectors from one of the horizontal planes are shown. Note the steering of the wind, reverse flow, and pockets of calm air that develop downwind of the buildings.

## The Impact: Secure Nuclear Facilities

Los Alamos National Laboratory's vulnerability assessment tools will help keep the nation's nuclear facilities safe and secure from accidents or potential terrorist threats.

# Nuclear Cross Section Measurements

## The Challenge: Transmuting Nuclear Waste

Radioactive waste may be destroyed through neutron absorption, but the rate of destruction depends on the material's propensity to absorb neutrons, or "cross section." Isotopes with high absorption cross sections transmute more readily in systems with high neutron populations. While cross sections of commonly used isotopes in conventional nuclear fuel are well known, they are less well known for isotopes of neptunium, americium, and curium, as well as some isotopes of plutonium. In turn, there is uncertainty in the performance of proposed transmutation systems, whether they are reactor-based or accelerator-driven. The work that Los Alamos is doing in measuring cross sections of major spent nuclear fuel constituents will reduce the uncertainty of the proposed transmutation system's performance and add confidence to the selection process.

## Los Alamos Innovation: Applying Unique Expertise and Instrumentation

The Los Alamos Neutron Science Center is without match for producing neutrons with kinetic energies from millielectron volts to hundreds of megaelectron volts with an array of detection systems unparalleled in the world. Los Alamos already has the instruments necessary to overcome obstacles, such as background from radioactive decay of the isotope. These instruments include

- **DANCE**—measures neutron capture cross sections;
- **GEANIE**—detects gamma rays emitted after neutron capture, giving insight into the nuclear structure of compound nuclei, and can be used to measure the inelastic scattering cross section of some isotopes; and
- **FIGARO**—measures higher-energy fission cross-sections and gamma rays emitted by neutron-induced nuclear reactions, and it detects secondary neutrons emitted by these reactions.

Los Alamos has the expertise in fabricating and handling the actinide targets necessary for these measurements.

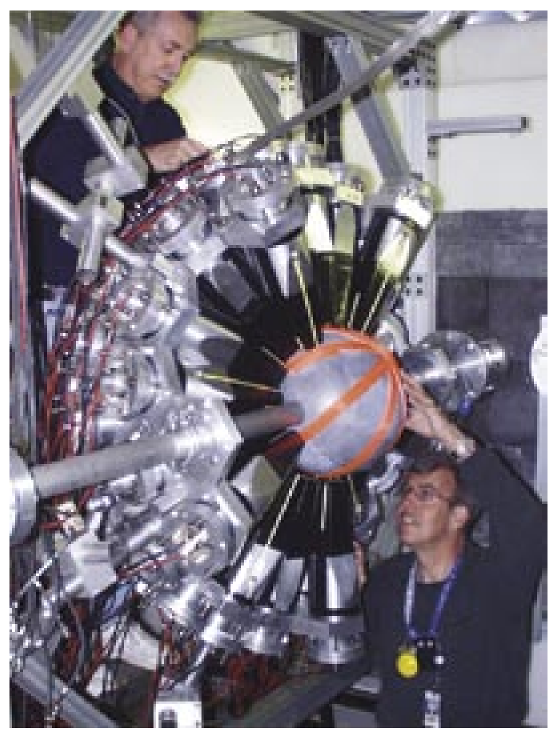
## The Impact: Assessing Transmutation System Performance

Los Alamos's effort to measure the capture and fission cross sections of the minor actinides involves

- Fabrication of radioactive samples;
- Preparation of safety documentation;
- Acquisition of data from experiments;
- Analysis of experimental data; and
- Publication of the results.

This effort is a natural fit with other Los Alamos capabilities, especially those of the Nuclear Data and Theory group which will aid in choosing the cross sections to be measured. They are the primary users of the experimental results that will ultimately be obtained. Researchers in the Systems Engineering and Integration group, and worldwide, will use the developed and evaluated nuclear data to assess the performance of proposed transmutation systems.

The newly commissioned DANCE detector. The radioisotope whose capture cross section is to be measured is placed in the center of the red-taped spherical sample chamber. Gamma rays emitted as a result of neutron capture in this sample are detected in the barium fluoride scintillators that completely surround the sphere (a so-called "$4\pi$ detector geometry"). In this photograph, half of the scintillators are moved away to allow access to the sample chamber.





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# Coolant Technology for Nuclear Systems

## The Challenge: Enhancing Safety and Reliability in Nuclear Coolant Technology

Nuclear coolant technology is considered to be one of the most critical and challenging issues in developing advanced nuclear systems, as can be seen in the Accelerator Transmutation of Waste (ATW) and Gen IV roadmaps. Safe and reliable nuclear coolant technology is a necessity. Mitigating safety issues of chemically active coolants, lead, lead-bismuth eutectic (LBE), and lead alloys—used as liquid metal coolants—represent a promising option in the liquid metal cooled waste transmuters and advanced reactors. Lead alloys are also potential target materials and coolants for high-power spallation neutron targets with multiple applications in accelerator-driven systems (ADS) and materials irradiation test facilities. This project targets the technology gaps for programmatic applications identified through analyses of the current state of the Lead-Bismuth Eutectic (LBE) technology, which is based on the Russian LBE nuclear coolant technology and the international ADS LBE technology development.

## Los Alamos Innovation: Developing Lead-Alloy Coolant Technology and Materials

Los Alamos boasts a suite of research & development tools to

- Develop, calibrate, and test oxygen sensors;
- Characterize protective oxide films on steels and their irradiation behaviors;
- Model system corrosion kinetics in oxygen-controlled liquid metal systems;
- Develop active corrosion probes; and
- Adapt reactor safety code for systems cooled by lead alloys.

Among the unique test facilities and technologies at the Laboratory's disposal, Los Alamos's DELTA LBE test Loop is the only one of its kind in the United States, and one of very few outside of Russia. A medium-scale forced circulation LBE loop for materials and thermal hydraulics testing, the DELTA Loop allows for simultaneous testing of large arrays of materials by featuring

- Sophisticated design and engineering,
- Versatile instrumentation and control, and
- Implementation of coolant chemistry control.

The DELTA Loop Test Facility including support, enclosure, and access structures. The data acquisition and control console are in front of the enclosed loop experimental apparatus. The DELTA Loop has been used in continuous corrosion test campaigns since the early part of 2003.

## The Impact: Reducing Risk and Producing Hydrogen

Coolant technology development is leading to other programs, which include

- Assisting AFCI and Gen IV in selecting technological options with reduced risks;
- Expert presence in Gen IV road mapping ensures lead-alloys-cooled fast reactors are properly evaluated and selected as one of six systems for further development;
- Capability to support the choice of lead-alloy-cooled systems for small, modular, deployable reactors; and
- Wider application of test facilities, materials, sensors, instrumentation, and control techniques developed for nuclear coolant.

Using liquid metal as a reforming medium may lead to alternative hydrogen production processes with reduced greenhouse gas emissions and automatic carbon sequestration, supporting the national hydrogen initiative and emphasizing nuclear and solar productions.

# Magnetized Target Fusion

## The Challenge: Developing Clean, New Energy Sources

The field of fusion energy research has been an endeavor of the U.S. government for nearly half a century. In the 1950's, through the efforts of Dr. Jim Tuck and "Project Sherwood," Los Alamos National Laboratory became controlled fusion's birthplace (ahead of Princeton by about 1 year). From the 1970's-1990, this research was carried on through the Controlled Thermonuclear Research (CTR) Division, and it continues today at modest levels in the Physics, Theory, and Chemistry Divisions.

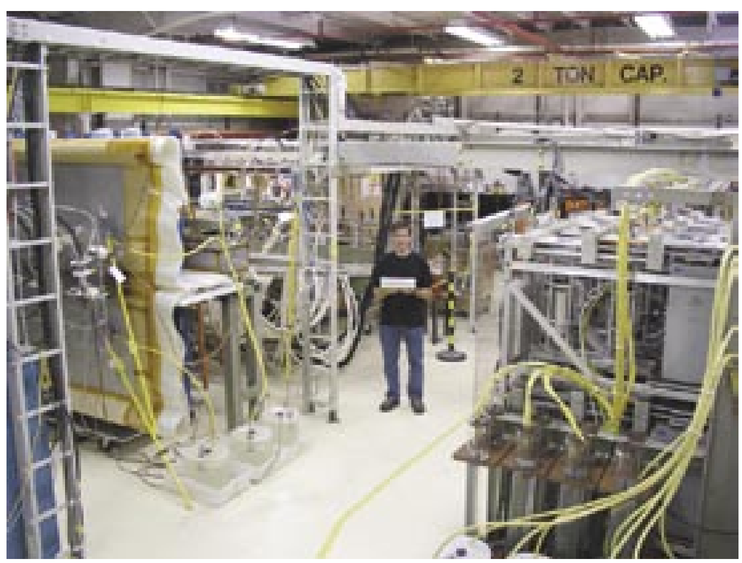
## Los Alamos Innovation: Magnetized Target Fusion

In the Physics Division, Los Alamos is pursuing a radical approach to achieving a hot fusion plasma in the laboratory through "magnetized target fusion" (MTF), involving ideas from traditional magnetic fusion confinement and inertial fusion confinement. Magnetized Target Fusion involves forming a moderately warm, moderately dense hydrogenic plasma. Los Alamos proposes stuffing this "target plasma" into an aluminum can, which is quickly compressed by an electric current running down the can's walls. The resulting electromagnetic "J x B" force crushes the can in a precise, controlled fashion. Los Alamos and the Air Force Research Laboratory (AFRL) in Albuquerque have can-crushing pulsed power machines developed for defense programs testing. With 20 years of experience with compact toroid fusion plasma combined with current advances made in liner technology, Los Alamos and the AFRL hope to make the first physics demonstration of magnetized target fusion within 4 to 5 years.

## The Impact: A New Energy Alternative for the Future

Fusion energy research is a challenging, multi-faceted project requiring the efforts of many scientists and engineers in collaboration throughout the world. Los Alamos aims to produce fusion-grade plasma quickly and cost effectively by mostly using existing facilities. A long-term vision for the MTF project is for the creation of a liquid-walled fusion reactor based on the MTF principles. This reactor would give a pulse of fusion energy every 10 seconds, with a new liner dropped into place between pulses and new target plasma injected into the liner. Before such a reactor could be realized, significant advancements must first be achieved in materials, sensors, controls, and engineering.

With the severity of long-term energy needs, persistence is key. Nuclear energy is split into fission and fusion energy. Fission reactors already produce significant electrical power to the grid, while fusion researchers can only talk about a 35-year plan to demonstrate the first power producing fusion reactor demo. Success in a project like MTF, offering an "orthogonal" approach to achieving fusion quicker and cheaper, would be a first step toward making a fusion reactor quite differently than presently planned by the scientific community.




FRX-L plasma injector experiment at Los Alamos National Laboratory. A researcher holds an aluminum liner.

# Future Directions

## A Nuclear-Powered Future and the Role of the United States

A reliable energy supply is vital to modern civilization. The availability of unfailing energy sources underpins our national security, economic prosperity, and global stability. There are signs, however, that our current energy supply is not reliable. Our world may soon see unprecedented new demands for energy leading to resource depletion, conflict, and increased pollution. As one of the world's most powerful and prosperous nations, the U.S. must accept its role in developing a diverse energy supply system that meets rapidly growing world energy needs while promoting peace, prosperity, and environmental quality. Experience and independent studies tell us that no single resource will meet all our future energy needs in an economically and environmentally acceptable way.

## Los Alamos National Laboratory Nuclear Program Goals

Despite the social stigma, nuclear energy has much to offer. Today, the 103 nuclear power plants operating in the U.S. produce more than 20 percent of the nation's electricity. The average plant operating costs for nuclear power are less than for coal, and about one-third of those for natural gas. Nuclear-generated electricity produces none of the greenhouse gases and smog-producing chemicals released when coal and natural gas are burned, and nuclear fuel supplies are abundant and secure. Resuming U.S. nuclear advancements, nuclear energy could

- Become an energy source for producing hydrogen necessary to realize a zero emissions transportation system;
- Reduce the United States' $CO_2$ emissions by more than 3 billion tons per year, halving the emissions currently produced by electricity generation;
- Replace 2 billion barrels of imported oil per year with nuclear-generated hydrogen (the U.S. imports about 3.5 billion barrels per year);
- Enhance our nation's energy security;
- Make up half the U.S. electricity and a quarter of the hydrogen for transportation;
- Reduce long-lived nuclear waste by more than 98 percent; and
- Reduce the risk of nuclear materials getting diverted to weapons use.

## Los Alamos National Laboratory Capabilities

Congress approved Yucca Mountain, Nevada as the used nuclear fuel repository. While a significant step, the current rate of waste production would require a repository the size of Yucca Mountain every 30 years (every 15 years if nuclear energy grows at 1.5 percent per year). The Nuclear Waste Policy Act directs the Secretary of Energy to decide on a second repository between 2007 and 2010. Providing an alternative solution to subsequent repositories, the Advanced Fuel Cycle Initiative (AFCI) proposes the recycling of used nuclear fuel, reducing the long-lived nuclear waste and capturing the remaining energy potential. Over 96 percent of spent nuclear fuel is uranium, the remainder being fission products, plutonium, and higher actinides. The AFCI's plan is to reuse the uranium, allowing short-lived fission products to decay, recycle, and transmute the plutonium and higher actinides. This greatly reduces the opportunity for diversion or misuse of nuclear materials because they are destroyed and not stored for millennia. This spent fuel treatment eliminates the need for additional repositories and reduces the risk of nuclear proliferation. These advanced technologies, combined with advanced techniques for transparent material accountability, will set future world standards for nuclear proliferation prevention and global nuclear materials management.

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